NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL MEMORANDUM

No. 1101

INVESTIGATIONS OF PRESSURE DISTRIBUTION ON FAST FLYING BODIES

By G. Stamm

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Untersuchungen uber den Druckverlauf um schnell fliegende Korper

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A. INTRODUCTION

The question to be treated is: how high is the pressure in the bow wave caused by a body flying at supersonic speed, and how far reaching are the destructive effects of that wave? The pressure distribution on an s.S. and an S. projectile of normal speed has been ascertained already by the methods of measurement used at the Ballistic Institute of the Technical Academy of the German Air Forces. Now similar investigations of the conditions on especially fast-flying bodies were carried out.

I. Experiments

(a) On the s.S. projectile.- The pressure in the single cross sections perpendicular to the axis of the projectile may be determined from an interferogram taken with Mach-Zehnder's interference-refractometer. The lines

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of equal pressure in a projectile flying with a speed of $v = 780$ meters per second (cal. 7, 9 mm) are shown in figure 1.

The rise in temperature caused by the (approximately) adiabatic compression corresponds to the increase in pressure. At 0.1 atmosphere there results a rise in temperature of 10° C, at 0.4 atmosphere an increase of 30° C. At the foremost point of the nose of the projectile the surface is perpendicular to the direction of the flow. We assume for this immediate region the values of pressure and temperature of a plate in perpendicular flow. There results an increase in pressure of 6.5 atmosphere and a rise in temperature of about 300° C.

<u>(b) On a projectile with a speed of $v = 1550$ meters per second.</u>- Another projectile with double the speed ($v = 1550$ m/sec and cal. 7, 9 mm) was examined and compared with the s.S. projectile. Figure 2 shows the interference picture for that projectile. This picture is very similar to the one shown by projectiles flying more slowly, except for an increase in the disarrangement of interference fringes and a decrease of the angle of the bow wave.

Figure 4 shows the course of the pressure distribution. As was to be expected, the boundary pressure of the bow wave increases about four-fold (that is with v^2) compared with the boundary pressure at half the speed ($v = 780$ m/sec). The increase in temperature caused by the (approximately) adiabatic compression (without consideration of the friction) also can be inferred from figure 4. These relations can be transferred to other calibers of a geometrically similar body. There is only one condition to be met for similar flows at supersonic speed: The Mach numbers $M = v/a$ for corresponding points of the flow to be examined and the model flow have to agree. Pressure, density, and velocity at geometrically similar points are retained. The relations change only in places where the friction is of importance as for instance the surface of the projectile.

II. Theoretical Results

According to Prandtl's formula for dynamic pressure the result to be expected for the nose of the projectile can only be an increase in pressure with v^2. According to Prandtl the increase in pressure at the stagnation point is

$$p = \frac{1}{2}\rho n v^2$$

The correction factor assumes up to the Mach number 3 the value 1.8 and converges, for higher Mach numbers, toward the value 1.84. This means that the pressure within the range of the Mach number from 0 to 3 increases somewhat faster than with the square of velocity. In all other regions, however, the pressure is proportional to v^2. Therefore, the highest possible pressure at the nose is 28 atmospheres ($M = 4.5$).

The theory of conical projectiles also proves that, for higher Mach numbers, the value $\frac{\Delta p/p}{k(v/a)^2}$ approaches a constant value (compare fig. 5). (The value $\frac{\Delta p/p}{k(v/a)^2}$ gives a measure for the pressure at the surface of the projectile which is certainly always higher than the pressure at the bow wave.) From this fact there results:

$$\Delta p/p = \text{prop. } (v/a)^2 = \text{prop. } v^2$$

III. Comparison of the Pressure Effect of the Bow Wave With the Pressure Effect of a Shock Wave Caused by an Explosive

An example will show how to compare the two effects.

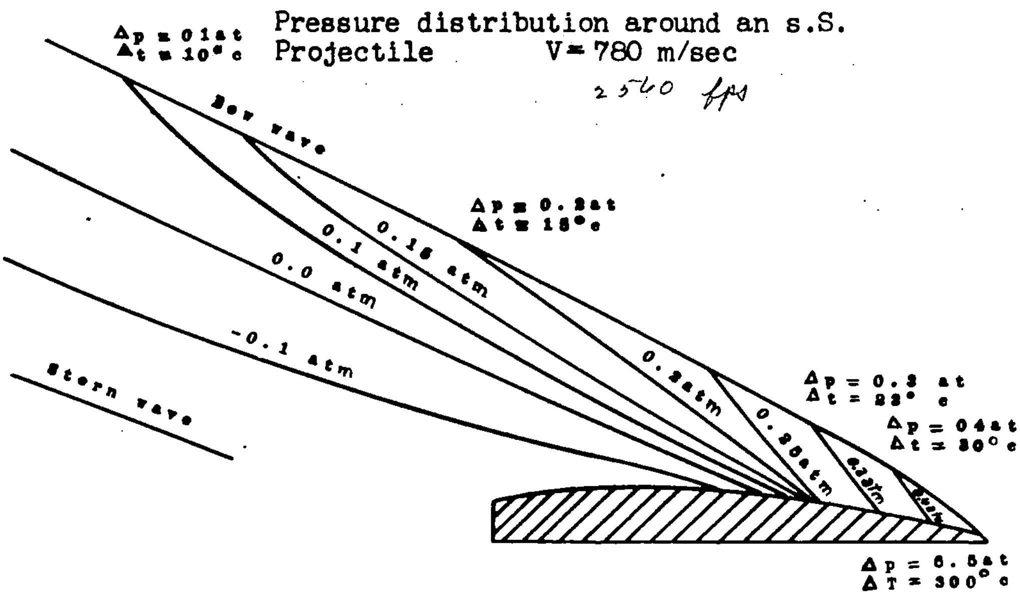
The caliber of the projectile shall be 180 centimeters. The shock wave spreads perpendicular to the bow wave at about sound velocity. The pressure distribution is similar to the one in a detonation. (Pressure distribution for a cross section g in 9 cal. distance from the nose of the projectile.) (See fig. 4 and fig. 6.)

The time elapsing from the pressure drop to the pressure 0 atmosphere is about 3 to 4 meters for all cross sections. The destruction of for instance a window pane depends on the length of time it is exposed to pressure as well as on the magnitude of the pressure striking upon it. The necessary pressure is 0.5 atmosphere; this figure results from the diagrams on the duration of excess pressure as a function of the distance that were obtained at the Ballistic Institute of the Technical Academy of the German Air Forces Gatow and from the characteristic lines of destruction for window panes as a function of pressure, distance, and quantity of explosive matter that were ascertained there also. This pressure occurs so close to the projectile that it is still recorded in figure 4. At a caliber of 1.8 meter the pressure of 0.5 atmosphere appears at a distance of 3 meters from the projectile. Not more than about 20 g of explosive would be necessary to destroy a window pane at that distance. If the destruction of objects other than window panes is intended these observations can be carried out only when the characteristic lines of destruction are known. One then will probably obtain no longer an amount of bursting charge of 20 g. But the new result will not differ essentially from the former one.

SUMMARY

A projectile with the speed of $v = 1550$ meters per second was expended in order to test how far reaching the destructive effects caused by the bow wave of an especially fast-flying body will be. The pressure distribution around the projectile was measured by means of an interference method. The result was that the pressure increases with about v^2 and that the destructive effects caused by the bow wave can be attained, even at a caliber of 1.8 meters, by a quantity of explosive matter no larger than about 20 g.

Translation by Mary Mahler
National Advisory Committee for Aeronautics



Pressure distribution around an s.S. Projectile V = 780 m/sec
2540 fps
Δp = 01at
Δt = 10° c
Bow wave
Δp = 0.2at
Δt = 18° c
0.15 atm
0.1 atm
0.0 atm
-0.1 atm
Stern wave
0.2atm
0.25atm
Δp = 0.3 at
Δt = 23° c
Δp = 04at
Δt = 30° c
Δp = 6.5at
ΔT = 300° c

Figure 1.

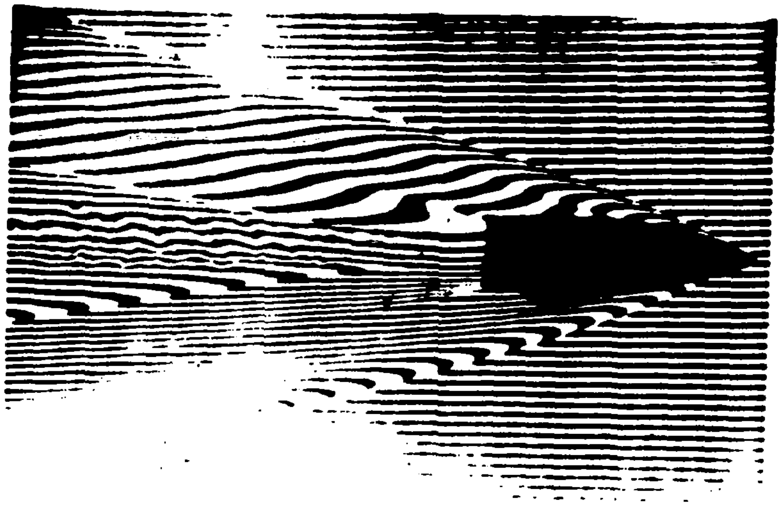


Figure 2.

Figure 3.

Pressure distribution around a projectile
V=1550 m/sec
5080 fps

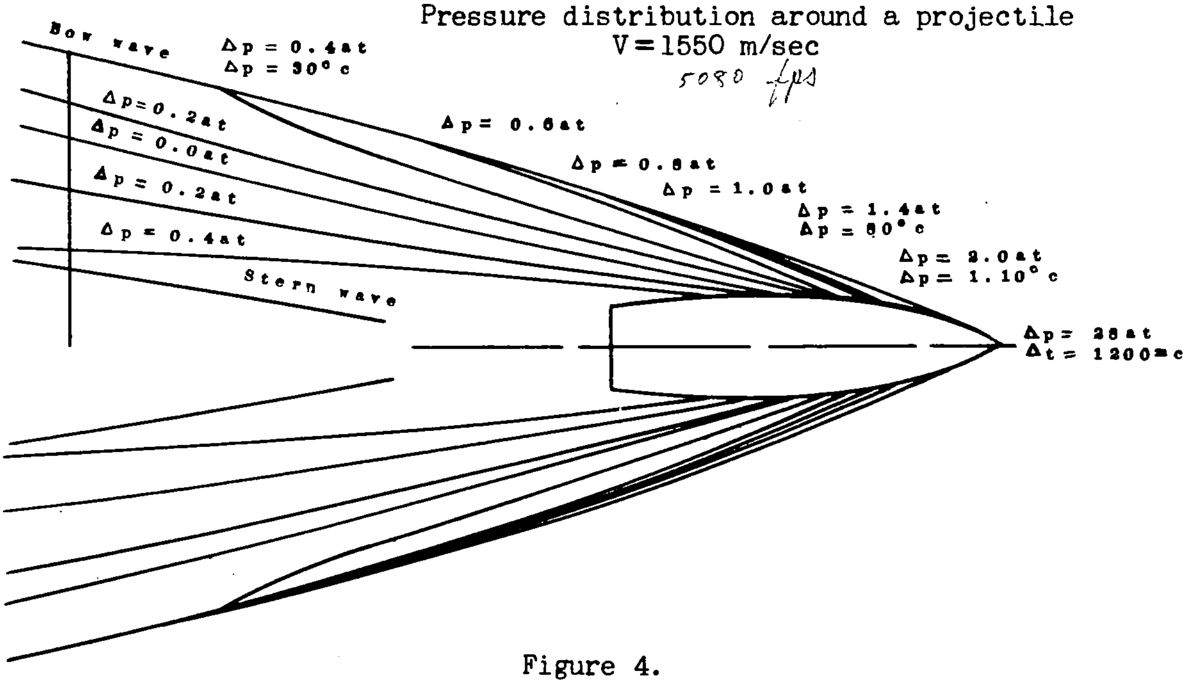


Figure 4.

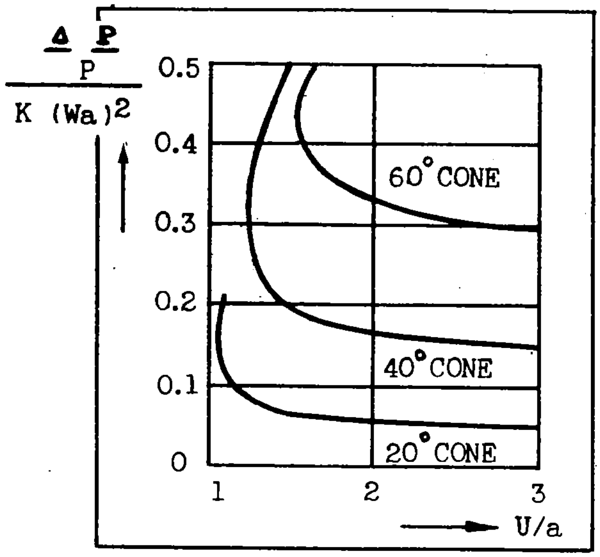


Figure 5.

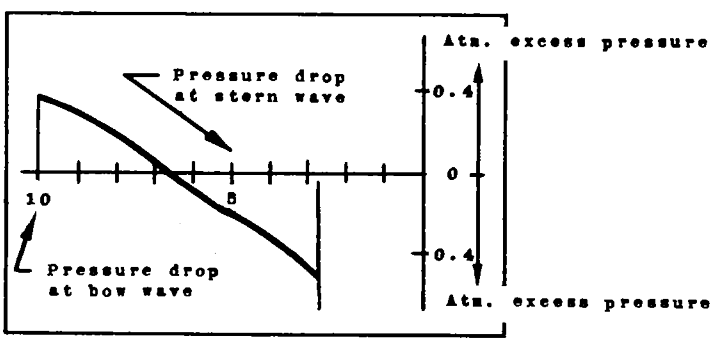


Figure 6.